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**Preliminary Assessment of a Microfiltration / Reverse Osmosis
Process for the Treatment of Landfill Leachate**

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**Preliminary Assessment of a Microfiltration / Reverse Osmosis
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Abstract

Landfill leachate may contain a variety of toxic inorganic and organic contaminants that are difficult to treat by conventional processes. A potential two stage precipitation/microfiltration (MF) and reverse osmosis (RO) process has been evaluated for its suitability in the treatment of landfill leachate. Experiments demonstrated that the precipitation/microfiltration process can be used to remove suspended solids, metals and hardness from raw leachate water generating a product stream suitable for further treatment by reverse osmosis. Membrane flux varied greatly with the precipitation methods used but a stable flux of 170 liters/m²/hour (LMH) was obtained at recoveries of up to 80%. Reverse osmosis experiments demonstrated the capability of RO in removing residual organics and dissolved solids. Total organic carbon (TOC) and conductivity of 500 mg/l and 7.6 micromhos in the feed to the RO were reduced to 30 mg/l and 0.2 micromhos in the RO permeate. Stable flux rates in excess of 27-30 LMH were obtained at recoveries up to 50% with leachate treated by microfiltration. The processes evaluated can also be useful in the treatment of a variety of complex industrial waste streams.

1.0 Introduction and Background

In recent years, the occurrence of a wide variety of organic and inorganic contaminants in ground and surface water has become recognized as a significant environmental concern by regulatory agencies. Toxic and hazardous compounds can originate from landfill leachates as a result of the soluble components of solid and liquid wastes being leached into surface and groundwater.

Often these landfill leachates are comparable to complex industrial waste streams which contain both toxic organic and inorganic contaminants. In cases where drinking water supplies may be impacted or where there is surface breakout, remedial actions must be undertaken. At some landfill sites leachate which is collected is discharged to municipal sewers for treatment in conventional sewage treatment processes. At other landfill sites where sewer lines are not available the leachate water may be hauled off site for treatment, may be recycled back to the landfill site or may be discharged to a surface water source. Hauling leachate for treatment by conventional processes is expensive and new regulations may limit the discharge of such complex wastes to municipal sewers since the nature of the contaminants are often not appropriate for treatment in conventional municipal biological processes. Recycling leachate within the landfill site itself can reduce the amount of liquid leaving the site but can only provide a short term solution. Effective and inexpensive methods of treating the material need to be developed.

Cross flow filtration processes including microfiltration (MF), ultrafiltration (UF) and reverse osmosis (RO) have been applied to the treatment of a wide variety of industrial waste water streams. Microfiltration processes with a filtration size of 0.1 to 1.0 microns remove suspended solids which are not easily settled and have been applied to the treatment of many wastewaters. In particular they have been successfully employed in the treatment of metal contaminated wastewater as the solids removal step after chemical precipitation of toxic metals. The MF process provides assured discharge water quality and is less susceptible to upset conditions than conventional solids removal processes.

Ultrafiltration processes which operate in a smaller filtration range (0.002 - 0.1 microns) are commonly used for the concentration of wastewater containing emulsified oils or large molecular weight organic contaminants.

Reverse Osmosis processes with a filtration range of less than 0.002 microns are used for the removal of dissolved solids and organic contaminants. Considerable work has been done evaluating the use of RO for the removal of problematic compounds in a variety of waste streams. Some of these include wastewater from electroplating, petroleum, petrochemical, pulp and paper and food processing plants. Researchers have also investigated the possibility of using reverse osmosis for the treatment of landfill leachates.

Chian and DeWalle (1976) of the University of Illinois studied leachate characteristics and related these findings to the most effective treatment method to utilize. Data analysis of the ratios of parameters such as BOD/COD and COD/TOC revealed that the leachate from young landfills containing mainly free volatile fatty acids can be degraded by biological means whereas old fills containing refractory organics were more effectively treated using physical/chemical methods. They also concluded that of all the physical/chemical methods evaluated reverse osmosis membrane treatment was the most effective in removal of COD from leachate water. They also concluded that appropriate pretreatment of leachate prior to reverse osmosis processing would be necessary to prevent severe membrane fouling.

Slater of Manhattan College and Ahlert and Uchirin of Rutgers University (1983) investigated different treatment trains in conjunction with RO to treat landfill leachates. Pretreatment consisted of the removal of bulk oil using gravity separation, coagulation using lime, recarbonation, then pH adjustment with sulfuric acid. After each chemical addition, the precipitate was allowed to settle before the supernatant was sent to the next treatment stage. The feed to the RO contained 16,400 mg/l of TDS, 26,400 mg/l of COD, and 8,480 mg/l of TOC. The product water from the pretreatment train still contained the majority of the organic matter and the inorganic salts. RO treatment effectively removed 98% of the TDS, 68% of the COD, and 59% of the TOC. The permeate flux averaged 7.5 LMH. Another pretreatment train investigated by these researchers (Slater et.al. 1986) involved lime coagulation, recarbonation, sedimentation, biological treatment and filtration prior to RO. The RO unit was operated in concentration mode. The initial feed TDS and TOC were 13,180 mg/l and 110 mg/l respectively. Treatment by RO was found to be effective with an average TDS removal of over 99%. TOC rejection increased during the testing from 70.8% to 94.7%. The permeate flux averaged 12 LMH at a recovery level (percent of feed flow discharged as clean water) of 63%.

In Canada, Environment Canada is the only public agency which has recently investigated RO for related applications. Over the last few years, a mobile self-contained RO unit has been used by researchers at the Environmental Protection Service (EPS) to demonstrate RO technology. Testing of this RO units at a municipal landfill site containing hazardous wastes from government laboratories demonstrated that RO was an efficient method for concentrating dilute organic leachates (Whittaker et.al., 1985). High removals of organic contaminants such as 1,1-dichloroethane (85.3%), 1,2 dichloroethane (85.5%), diethyl ether (77.2%), 1,4-dioxin (86.6%) were achieved at recovery levels in excess of 90%.

This current project involves the assessment of a two stage process for the treatment of landfill leachates involving precipitation and microfiltration for removal of toxic metals and suspended solids and concentration of residual organics by reverse osmosis. The first step precipitation/microfiltration provides a simple pretreatment process prior to RO. The solids generated in this first stage of the process can be dewatered in a plate and frame or similar filter press and solidified prior to final disposal. The treated water is free of suspended solids which if present would cause problems in the operation of the RO system.

The RO process concentrates the residual organics and dissolved solids and generates a treated water stream with only very low levels of organic contaminants. The concentrated organics may be recycled back to the landfill site where natural biological activity will degrade much of the organic fraction. The biological activity will be enhanced as a result of the reduced level of metals which can inhibit biological degradation. The clean water discharged will balance the water input via rainwater to allow for long term recycle of leachate without excessive build up of water at the site. A process flow schematic for the proposed process is shown in Figure 1.1.

This work has been conducted to evaluate the efficiency and determine operating parameters for each of the steps in the process.

2.0 Experimental Program

2.1 Microfiltration Experiments

Microfiltration experiments were conducted using samples of leachate collected from a landfill site in Southern Ontario. The test equipment consisted of a membrane test unit for 13 mm diameter tubular membranes, a 50 liter process tank, a recirculation pump, interconnecting piping and controls for maintaining the desired operating temperature, pressure and flows. The microfiltration membranes used were manufactured by ZENON Environmental Inc. The equipment could be operated with the permeate recycled to the process tank (stability mode) or collected in a separate tank (concentration mode). A sketch of the equipment used for these tests is shown in Figure 2.1. The membrane test unit allows for testing of six individual 300 mm long sections of 13 mm diameter tubular membranes. The membranes used were ZENON microfiltration

membranes. The fluid flow in the tubes is the same as that used in full scale tubular membrane modules and scale up from the small test unit is easily done. The flow through the 13 mm diameter tubes was maintained at 12 liters/min. and the inlet pressure was maintained between 207 - 241 kPa (30 - 35 psig).

Four different chemical precipitation treatment methods were used to precipitate the metals and other contaminants, from the raw leachate water in the five tests conducted. In the first one, caustic soda (sodium hydroxide) was added to the raw leachate to a pH of 10. In the second and fourth test the pH of the leachate was adjusted to 10 by the addition of lime. In the third test, the pH was adjusted to 10 with lime, and 20 g/L of powdered activated carbon (PAC) was also added. In the fifth and final test the pH was adjusted to 10 with lime. Soda ash (sodium carbonate) was also added in this final test to assist in the removal of calcium and magnesium.

In the first three experiments, the microfiltration process was operated in a stability mode with all the treated water or permeate recycled back to the process tank. In the final two experiments, the permeate was collected and the suspended solids in the feed were concentrated by a factor of 10. This concentration represents a 90% recovery since 90% of the volume in the feed was recovered as clean or treated water.

Chemical analyses were conducted on the raw leachate samples, and permeates generated. Flux or permeate rates were measured and recorded at regular intervals during each of the tests. The efficiency of the process in removing metals and organic contaminants was evaluated.

2.2 Reverse Osmosis Experiments

Reverse osmosis (RO) experiments were conducted using a sample of leachate water which had been processed by the precipitation/microfiltration pretreatment. In the pretreatment the pH of the raw leachate was adjusted to 10 with the addition of lime slurry. Soda ash was also added to assist in the removal of calcium. The resulting solution was then processed in the tubular microfiltration until 90% of the original volume of feed was collected as pretreated permeate. The pH of the MF permeate was adjusted to 5.5 by addition of HCl to reduce the potential for scale formation during reverse osmosis concentration. In this experiment the MF permeate was also spiked with pentachlorophenol to assess the removal efficiency of this problematic contaminant.

The test equipment consisted of two spiral RO membranes connected in parallel, a 190 liter process tank, a high pressure recirculation pump, interconnecting piping and controls for maintaining the desired operating temperature, pressure and flows. As with the MF experiments the permeate could be recycled to the process tank (stability mode) or collected in a separate tank (concentration mode). A sketch of the equipment used for these tests is shown in Figure 2.2. The spiral RO membranes used were obtained from Filmtec (BW30-2514) and Nitto-Denko (NTR-729HF-52B).

A stability test and two batch concentration experiments were conducted to determine the flux rates and separations which could be obtained with the two different reverse osmosis membranes. The operating pressure of the membranes was maintained at 2,750 kPa and the temperature was maintained at 25°C. Samples of feed and permeate were collected and analyzed to determine the separation of contaminants in the RO process.

3.0 Results and Discussion

3.1 Microfiltration Experiments

The microfiltration flux obtained with the ZENON MF membranes during the first three short duration MF experiments are shown in Figure 3.1. As can be seen from the graph the flux obtained varied greatly depending upon the precipitation chemicals used. When lime was used to adjust the pH of the raw leachate, the MF membranes exhibited a high flux of approximately 254 LMH. When lime and powdered activated carbon were used together the flux was stable at approximately 170 LMH. When the pH was adjusted using caustic the flux was very low at less than 42 LMH. It is apparent that the method of chemical precipitation has a great impact on the flux which is obtained in the microfiltration process. The solids formed when caustic is used appear to have a greater tendency to adhere to and foul the MF membranes. The flux obtained with lime and lime plus activated carbon are slightly lower than is normally obtained with the MF membranes in standard metal precipitation processes but no abnormal levels of fouling appear to be occurring.

The microfiltration flux obtained during the final two longer duration MF experiments with lime and lime plus soda ash are shown in Figure 3.2. This graph shows the flux during concentration of the feed to one tenth its original volume (90% recovery). The flux for test #4 when

lime alone was used was stable at 170 LMH during most of the concentration cycle. The flux did however decline rapidly after the 80% volume reduction point. This loss in flux at high concentration may be the result of fouling of the membrane which occurs when a high concentration of some slurry component is present. The flux for test #5 when lime and soda ash were both used as precipitation chemicals was stable near 85 LMH for the latter half of the concentration run. The flux was lower than the previous test but did not decline during the final concentration to 90% volume recovery. As in the first set of MF experiments, the flux is highly dependent upon the precipitation chemicals used.

The performance of microfiltration membranes are affected by the chemicals used and by the specific chemistry of the membrane polymer and membrane additives used. Certain additives can repel particular compounds which may be causing fouling of the membrane and allow for much higher and more stable flux rates to be obtained. The results obtained here are for one type of microfiltration membrane chemistry and optimization of the particular membrane chemistry may yield higher and more stable flux for this particular application. Optimization of the dosage of the precipitation chemicals will also likely result in improved membrane performance.

The results of chemical analysis on raw leachate and microfiltration permeate from the first three MF experiments are shown in Table 3.1. As expected total suspended solids (TSS) were virtually completely removed by the microfiltration process with all of the chemical precipitation method while total dissolved solids (TDS) shows almost no reduction. Total Organic Carbon (TOC) levels were reduced slightly (10 - 11%) with use of caustic and lime and somewhat more (32%) with the combined lime plus carbon treatment. Total organic halogens (TOX) were reduced to a considerably higher degree than the rest of the organic carbon particularly when activated carbon was used in addition to the lime. Calcium was removed almost completely when caustic (NaOH) was used to adjust the pH but very little when lime ($\text{Ca}(\text{OH})_2$) which contains additional calcium was used. Few metals were present in the raw leachate sample but iron was present at 130 mg/l. Iron was completely removed by microfiltration after treatment by all three precipitation methods used. Xylene and toluene were present in the raw feed and appear to have been completely removed in the microfiltration process. This reduction may be due to the organics being associated with solids which are rejected or may be the results of loss due to volatilization. Longer term testing with large sample volumes will be required to determine the actual rejection of these organics.

The results of chemical analysis on raw leachates and MF permeate from the fourth and fifth MF experiments are shown in Table 3.2. As was seen in earlier experiments, suspended solids are removed but dissolved solids pass through the microfiltration membrane. Organic carbon was reduced only slightly and organic halogens as measured by TOX were not reduced at all. The major difference in the MF permeate after pretreatment with lime and lime plus soda ash are in the levels of calcium and alkalinity which are both significantly less when soda ash was used. The addition of soda ash has had the desired effect of softening the water to make it more suitable treatment in the RO polishing process.

3.2 Reverse Osmosis Experiments

The flux for the Filmtec and Nitto membranes during the two batch concentration experiments are shown in Figure 3.3. The flux for the Filmtec membrane remained virtually the same for both the concentration tests at 27 - 30 LMH. There was a slight decrease in the flux during the concentration but this flux loss was recovered when fresh dilute feed was processed in the subsequent batch. This suggests that the flux loss was due to changes in the material being processed during concentration rather than serious fouling of the membrane. The flux for the Nitto membrane at the end of the first concentration run was 30 LMH but increased significantly during the second batch concentration to 47 LMH.

The recovery during the test was limited to 50% since in this application the concentrate may be easily disposed of by recycle back to the landfill site. The flux was still stable at this 50% recovery level and in other wastewater applications where disposal of concentrate is more difficult it may be possible to increase the recovery level without significant loss in flux.

During each of the batch concentration runs, samples of permeate were collected and the conductivity was measured. Table 3.3 shows the conductivity of the feed and permeate collected during the two batch concentration runs. The rejection of conductivity for the Filmtec membrane was consistently 99% or better. The rejection of conductivity for the Nitto membrane was considerably lower and decreased significantly at the end of the 2nd concentration run. This loss in conductivity rejection and increase in flux may be due to some deterioration in the membrane as a result of exposure to the leachate solution or may be the result of a small leak around some mechanical seal in the membrane module itself.

As a result of the consistent flux and high conductivity rejection, more detailed chemical analysis was conducted on the permeate from the Filmtec membrane generated during the final batch concentration test. Results of this analysis are shown in Table 3.4. Measurements of organic content including TOC, BOD and TOX showed virtual complete rejection (98%) or organic compounds. All inorganic compounds which were present above the minimum detection limit with the exception of boron showed rejection of at least 97%. Very few heavy metals were present in the original feed and those that were present were removed in the precipitation microfiltration pretreatment. The RO rejected virtually all (98%) of the dissolved solids as measured by conductivity from the RO feed.

The feed to the RO system had been spiked with pentachlorophenol (PCP) and toluene. The feed to the RO contained 430 ppb of PCP and 320 ppb of toluene. The permeate contained 30 ppb of PCP and 100 ppb of toluene demonstrating 93% rejection of PCP and 69% rejection of toluene.

The reverse osmosis experiments demonstrated the feasibility of RO for the concentration of residual organics and dissolved solids present in the permeate from a microfiltration process. The flux for the Filmtec membrane was stable through the duration of the testing. Rejection of organics as measured by general parameter of TOC, BOD and TOX was excellent. Rejection of volatile organics such as toluene were significant but somewhat lower.

4.0 Conclusions

The results of this work has demonstrated the feasibility of a two step process for the treatment of landfill leachate containing a complex mixture of inorganic and organic contaminants. The first stage precipitation/microfiltration step was capable of removing suspended solids, metals and hardness from the raw leachate. These contaminants will interfere with the operation of RO systems downstream in the process and can reduce the rate of biodegradation of organics in the leachate if biological treatment is used. The process is resistant to upset and provides a consistent high quality product water required for RO processing. The RO process has been shown to be capable of concentrating virtually all the remaining organics and dissolved solids present from the first stage of treatment and generating a clean product water with very low levels of any problematic contaminants. The process of precipitation/microfiltration can be used for removal of suspended solids, metals and other contaminants in a variety of wastewater applications. With suitable pretreatment, reverse osmosis can be used as an important step in the treatment of many different

wastewater streams. Pilot testing of the proposed process needs to be conducted to confirm the efficiency of the process during longer term operation.

Acknowledgement

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FIGURE 1.1
Microfiltration / Reverse Osmosis Process For Leachate Treatment

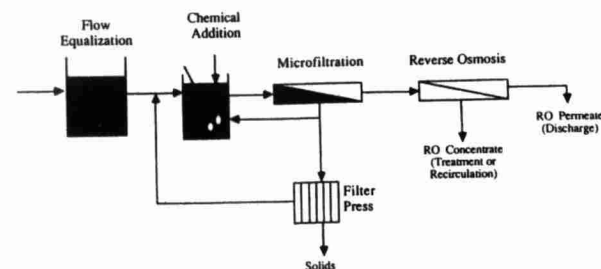


FIGURE 2.1
Flow Schematic of Microfiltration Test Equipment

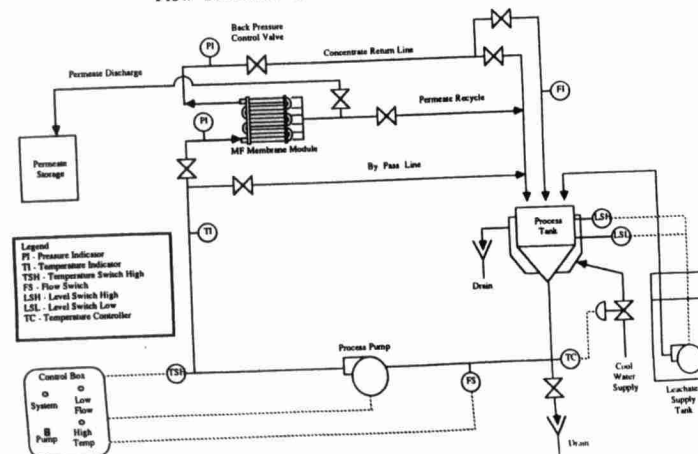


FIGURE 2.2

Flow Schematic For Reverse Osmosis Test Equipment

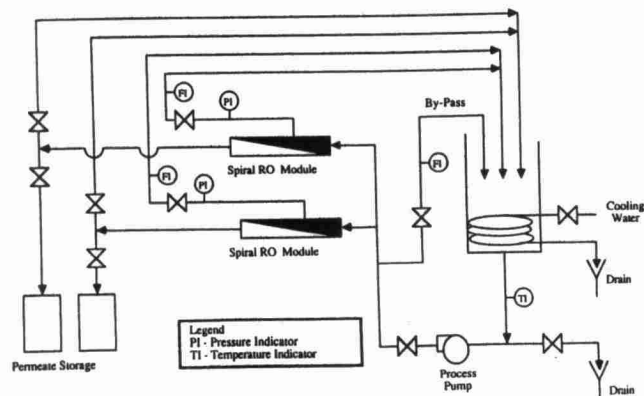


FIGURE 3.1

Flux Rates for Short Duration Microfiltration Experiments

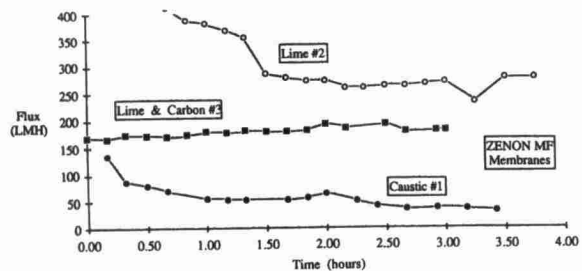


FIGURE 3.2

Flux Rates for Longer Duration Microfiltration Experiments

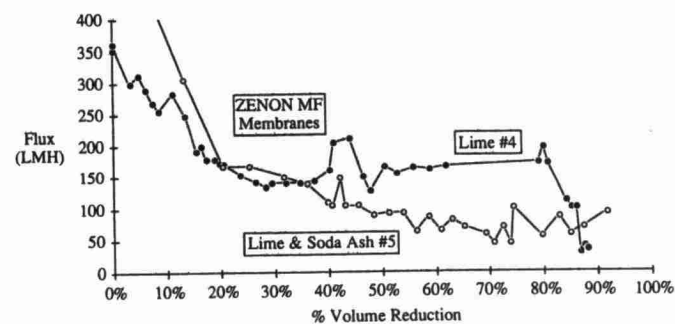


FIGURE 3.3

Flux Rates for Reverse Osmosis Concentration Tests

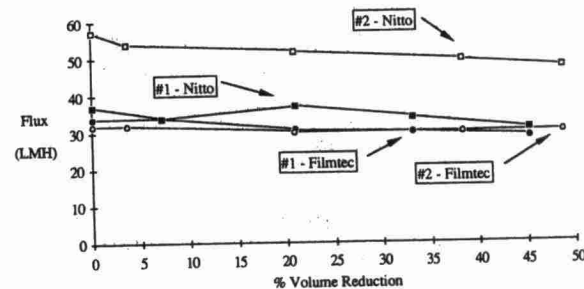


TABLE 3.1
Product Water Quality for Microfiltration Experiments 1, 2 & 3

Parameter	Test # 1		Test # 2		Test # 3	
	Raw Feed	% Rejection	Permeate	% Rejection	Permeate	% Rejection
pH	6.8	--	10	99%	9.9	--
TSS (ppm)	290	98%	2.7	16%	1.5	99%
TDS (ppm)	6930	-23%	5790	11%	4970	28%
TOC (ppm)	1900	10%	1690	86%	1290	32%
TOX (ppb)	228	52%	31.4	11%	4.3	98%
Calcium (ppm)	570	99%	510	63%	450	21%
Magnesium (ppm)	380	47%	<0.01	>99%	110	71%
Iron (ppm)	130	>82%	<0.02	>82%	<0.01	>99%
Xylene (ppm)	0.11	71%	0.02	86%	<0.02	>82%
Toluene (ppm)	0.14		0.04		<0.01	>93%

Chemical Pretreatment:

Test # 1 - Caustic to pH10.

Test # 2 - Lime to pH 10.

Test # 3 - Lime to pH 10 and 20 g/l Powdered Activated Carbon (PAC).

TABLE 3.2
Product Water Quality for Microfiltration Experiments 4 & 5

Parameter	units	Test 4			Test 5		
		Raw Feed	Permeate	% Rejection	Raw Feed	Permeate	% Rejection
pH		6.6	11.9	-	7.0	10.7	-
TSS (ppm)		430	21	95%	200	60	70%
Turbidity (NTU)		3.6	0.47	87%	24	0.6	98%
TDS (ppm)		6,100	6,680	-10%	-	-	-
Conductivity (mmhos)		5.07	6.86	-35%	4.14	4.80	-16%
TOC (ppm)		1,650	1,400	15%	-	-	-
TOX (ppb)		100	120	-20%	-	-	-
COD (ppm)		4,700	4,300	9%	-	-	-
BOD (ppm)		3,500	3,000	14%	-	-	-
Fluoride (ppm)		interference	interference			130	
Chloride (ppm)		670	930	-39%		3,600	
Nitrite (as N) (ppm)		<0.2	<0.2			<0.20	
Bromide (ppm)		<0.8	<0.8			<0.8	
Nitrate (as N) (ppm)		0.96	1.0	-4%		1.0	
Phosphate (as P) (ppm)		<0.8	<0.8			<0.8	
Sulfate (ppm)		380	390	-3%		<1.0	
Alkalinity (as CaCO3) (ppm)		2600	2800	-8%		240	
Calcium (ppm)		540	1100	-104%	400	22	95%
Magnesium (ppm)		240	1	>99%	340	140	59%
Sodium (ppm)		430	420	2%	560	2000	-257%
Potassium (ppm)		240	230	4%	250	260	-4%
Aluminum (ppm)		1	0.3	70%	0.75	<0.03	>96%
Barium (ppm)		0.063	0.071	-13%	0.75	0.003	>99%
Boron (ppm)		5.2	4.1	21%	5	3.6	28%
Chromium (ppm)		0.15	<0.1	>99%	0.075	0.012	84%
Iron (ppm)		79	<0.2	>99%	75	0.094	>99%
Manganese (ppm)		7.1	2.9	59%	4.5	0.007	>99%
Nickel (ppm)		0.15	<0.1	>33%	<0.05	0.074	
Phosphorus (ppm)		4.7	2.6	45%	3.7	0.96	74%
Silicon (ppm)		12	1.1	91%	10	3.3	67%
Strontium (ppm)		5.3	1.2	77%	5.9	0.18	97%
Titanium (ppm)		0.91	0.85	7%	<0.05	<0.01	
Zinc (ppm)		2.4	<0.1	>96%	2	0.019	99%
trans-1,2-Dichloroethene (ppb)		4.1	<3.0	>27%	<1.0	<1.0	
1,1-Dichloroethane (ppb)		60	<3.0	>95%	100	7.2	93%
1,2-Dichloroethane (ppb)		5.9	<3.0	>49%	25	2.7	89%
Benzene (ppb)		7.1	<3.0	>58%	59	5.7	90%
Toluene (ppb)		79	36	54%	550	320	42%
Ethyl benzene (ppb)		4.2	3.3	21%	79	1.5	98%
Tetrachloroethane (ppb)		8.1	<3.0	>63%	<1.0	<1.0	
Phenol (ppm)		3.9	1.1	72%			

Other Cations were less than detection limit.

Chemical Pretreatment:

Test # 4 - Lime to pH 10.

Test # 5 - Lime to pH 10 & Soda Ash.



TABLE 3.3

Conductivity of Reverse Osmosis Permeate

Test	Feed	Filmtec		Nitto	
		Permeate	% Rejection	Permeate	% Rejection
Concentration #1	13.8	0.19	99%	1.4	90%
Concentration #2	13.3	0.15	99%	2.17	84%

TABLE 3.4

Product Water Quality from Reverse Osmosis Experiment

Parameter	Unit	Spiked RO Feed	Filmtec Permeate	% Rejection
pH		6.1	5.2	-
TSS	(ppm)	-	-	-
Turbidity	(NTU)	6	0.4	93%
TDS	(ppm)	7500	-	-
Conductivity	(mmhos)	7.61	0.19	98%
TOC	(ppm)	1500	30	98%
TOX	(ppb)	200	2.1	99%
COD	(ppm)	5,900	-	-
BOD	(ppm)	4,900	35	99%
Fluoride	(ppm)	130	3.8	97%
Chloride	(ppm)	3,600	36	99%
Nitrite (as N)	(ppm)	<0.2	<0.2	-
Bromide	(ppm)	<0.8	<0.8	-
Nitrate (as N)	(ppm)	1.0	<0.20	>80%
Phosphate (as P)	(ppm)	<0.8	<0.8	-
Sulfate	(ppm)	<1.0	<1.0	-
Alkalinity (as CaCO ₃)	(ppm)	240	-	-
Calcium	(ppm)	22	0.076	>99%
Magnesium	(ppm)	140	0.38	>99%
Sodium	(ppm)	2,000	40	98%
Potassium	(ppm)	260	8.2	97%
Aluminum	(ppm)	<0.03	<0.03	-
Barium	(ppm)	0.003	<0.001	>66%
Boron	(ppm)	3.6	0.83	77%
Chromium	(ppm)	0.012	<0.01	>16%
Iron	(ppm)	0.094	<0.01	>89%
Manganese	(ppm)	0.007	<0.005	>28%
Nickel	(ppm)	0.074	<0.01	>86%
Phosphorus	(ppm)	0.96	<0.1	>89%
Silicon	(ppm)	3.3	<0.05	>98%
Strontium	(ppm)	0.18	<0.001	>99%
Titanium	(ppm)	<0.01	<0.01	-
Zinc	(ppm)	0.019	<0.01	>47%
1,1-Dichloroethane	(ppb)	7.2	<1.0	>86%
1,2-Dichloroethane	(ppb)	2.7	<1.0	>63%
Toluene	(ppb)	320	100	69%
Total Phenol	(ppb)	430	30	93%